REPORT TO THE FCC

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SCS MOBILECOM, INC.

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1.0 EXECUTIVE SUMMARY

This report considers the single, most important parameter in a Personal Communication System; *multipath*, and its effect on system performance.

It is shown that the received power lost due to fading (the fade margin) increases dramatically as the instantaneous bandwidth of a communication signal decreases below 11MHz. In particular, comparing the fade margins of a 1MHz and a 15MHz bandwidth signal, as in Fig. 3.4, shows a difference in fade margin of approximately 10dB.

In addition, using a modelling technique for out-of-sight communications, of the type typical for PCS, it was shown that multiple rays from a transmitter reach the receiver and only 1 to 3 of these rays have similar power levels. The remaining rays are attenuated by 3dB or more. It was also shown (see, for example, Fig. 4.6) that the narrower the bandwidth of the spread spectrum signal the larger the number of rays which can occur within a chip duration and which are therefore correlated. Hence the greater the likelihood of a deep fade.

Further, it is shown in Figs. 5.1 - 5.3, that the multipath observed in practice had almost all of its power concentrated in a time interval of 100 to 500ns following the largest return. This result was also verified by photographs of out-of-sight multipath obtained using a RAKE receiver. If, however, a distant multipath signal return is seen, due to the reflection from a mountain or some distant building (a situation far more likely in a rural setting rather than an urban setting), then, if this reflection was more than 1000 feet greater than the main signal ray returns, a 1MHz narrowband spread spectrum system could use a RAKE to collect this added reflected power.

While a wideband spread spectrum system could also use the RAKE to collect some additional energy, such collection is <u>required</u> by the narrowband system since its primary signal rays suffer the extra 10dB attenuation due to fading. Hence, it is not unlikely that in a narrowband CDMA system, the reflected power be of greater value than the in-close power, since both the in-close and far-out signals fade independently.

Based on the above theory and experiments, it is our conclusion that a wideband spread spectrum system, such as B-CDMA, be employed, which spreads the spectrum of the entire spectrum provided by the Commission. Such a system also provides ISDN data rates, high quality voice, and can work indoor, where multipath signals are delayed by small time intervals, as well as outdoor, all without suffering dropped calls; the parameters required for a Personal Communications Service.

During the next quarterly report, SCS will obtain additional data to further demonstrate the advantages of a wide spectral allocation and the benefits of B-CDMA.

2.0 INTRODUCTION

A transmitted signal spreads out as it leaves the transmitting antenna. If this signal is viewed as a "bundle" of signal rays, each carrying the same information, then these rays may be reflected off of objects such as buildings, the ground, cars, trees, people, etc., and some of these rays, after all of these reflections, are received at the intended receiver. The signal rays are attenuated as they propagate and attenuated at each reflected surface [1], so that the received rays each have different amplitudes. In addition, the received rays each have a different delay since they have each taken different paths and therefore travelled different distances.

It should be noted that the signal propagates at the rate of 1 foot/ns so that two rays received 1μs apart have travelled paths that differed by 1000 feet. In addition, in out-of-sight communications, the signal is attenuated by the 4th power or more [1] so that if, for example, a signal ray travels 3000 feet and a second signal ray travels 4000 feet, then the ratio of the powers are

$$\frac{P_{LONG}}{P_{SHORT}} = \left(\frac{3}{4}\right)^4 = 0.32\,(=-4.5dB)$$

Since the longer path ray has probably encountered more reflections than the shorter path ray, the longer path ray typically suffers additional attenuation due to these extra reflections.

A spread spectrum signal ray is uncorrelated to a second signal ray if the two rays are received, delayed from one another by more than the chip time. If the delay is less than the chip time, the two signals are correlated and they will add or subtract depending on the carrier phase. This is called multipath fading. We shall call such multipath signals, "close-in" multipath. If the delay exceeds a chip duration, the signal's are uncorrelated and their powers will add. In this latter case, the delayed signal "looks" to the spread spectrum receiver as a jamming (interfering) signal and creates noise. We shall call these type of multipath signals, "far-out" multipath.

A RAKE receiver is a multitude of spread spectrum receivers each of which synchronizes to a distinct, uncorrelated, ray (This assumes that these rays are delayed from one another by more than 1 chip). These received signals can then be combined coherently or noncoherently to increase the effective, received energy. For example, if the two received signals are of the same amplitude, a 3dB increase in signal-to-noise ratio is readily attainable. RAKE is a time diversity system using the inherent time diversity provided by a multipath environments. Hence the amount of improvement depends on the number of receivers (often called "fingers") and the method of combining.

In a typical system, a group of rays occur within the chip duration causing fading. However, a second (and perhaps a third, etc.)

group of rays occur after a "significant" delay, i.e., a delay greater than the chip duration. These rays, too, produce a fading signal. However, the two, or more, resultant, fading signals are uncorrelated with each other. The RAKE receiver can combine these uncorrelated signals.

If "close-in" multipath did not exist, the two signals would differ significantly in power and therefore no significant advantage would occur from using a RAKE receiver. This is the case, if the chip duration is small, since it is then less probable for "close-in" multipath to occur.

In the case of a long duration chip (which occurs when the bandwidth of the spread spectrum signal is small), the probability of close-in multipaths is significantly more probable. A RAKE receiver would help such a system's performance if, in addition to the first set of close-in signal rays, a second set of signal rays occurred as a result of a distant reflection. Then, it is probable that during a certain time interval the first-received (shorter path) signal may fade and become very small while the distant rays, fading independently, may become large. If a RAKE receiver was not used, the bit error rate during this time period could be very high. However, if RAKE is used, the longer-path (far-out) signal is also received and the bit error rate performance is improved.

To verify these heuristic results, SCS performed a significant number of experiments, in offices, large buildings, outdoor in the suburbs and outdoor in New York City. Chapter 3 describes the results of experiments performed to measure the amount of signal power lost during a fade (this is called the fade margin needed by a spread spectrum signal) as a function of bandwidth. Chapter 4 presents a theoretical model for out-of-sight communication which shows the amplitudes and relative delays of the multipath rays collected at a single receiver. Chapter 5 shows the relative delays of the multipath components measured in out-of-sight communication, indoor and outdoor. Chapter 6 presents the Conclusions.

3.0 ENVIRONMENT SPECIFIC FADE MARGIN OF SPREAD SPECTRUM SIGNALS AT 1.9GHz

3.1 Introduction

In this section, the signal power, lost due to fading (the fade margin), required for spread spectrum systems as a function of bandwidth, is presented.

Experiments were performed within buildings, in offices, outdoor in the suburbs and outdoor in New York City.. Approximately one million data points were processed to obtain the curves shown below.

3.2 Experimental Results

Figures 3.1, 3.3, and 3.5 show the probability of the received signal power differing from the mean signal power by more than a prescribed amount, called the fade margin as a function of bandwidth. For example, in Fig. 3.1, the data was taken in the suburban community of Port Washington, NY. For a bandwidth of 11MHz, the probability is 10^{-3} that the received signal's power will fade by more than 10dB from its mean value.

The results shown in this figure, for the bandwidths of 11, 22, 30 and 48MHz all yield similar results. However, the fading at 2MHz and for a CW signal show that very large fade margins are needed.

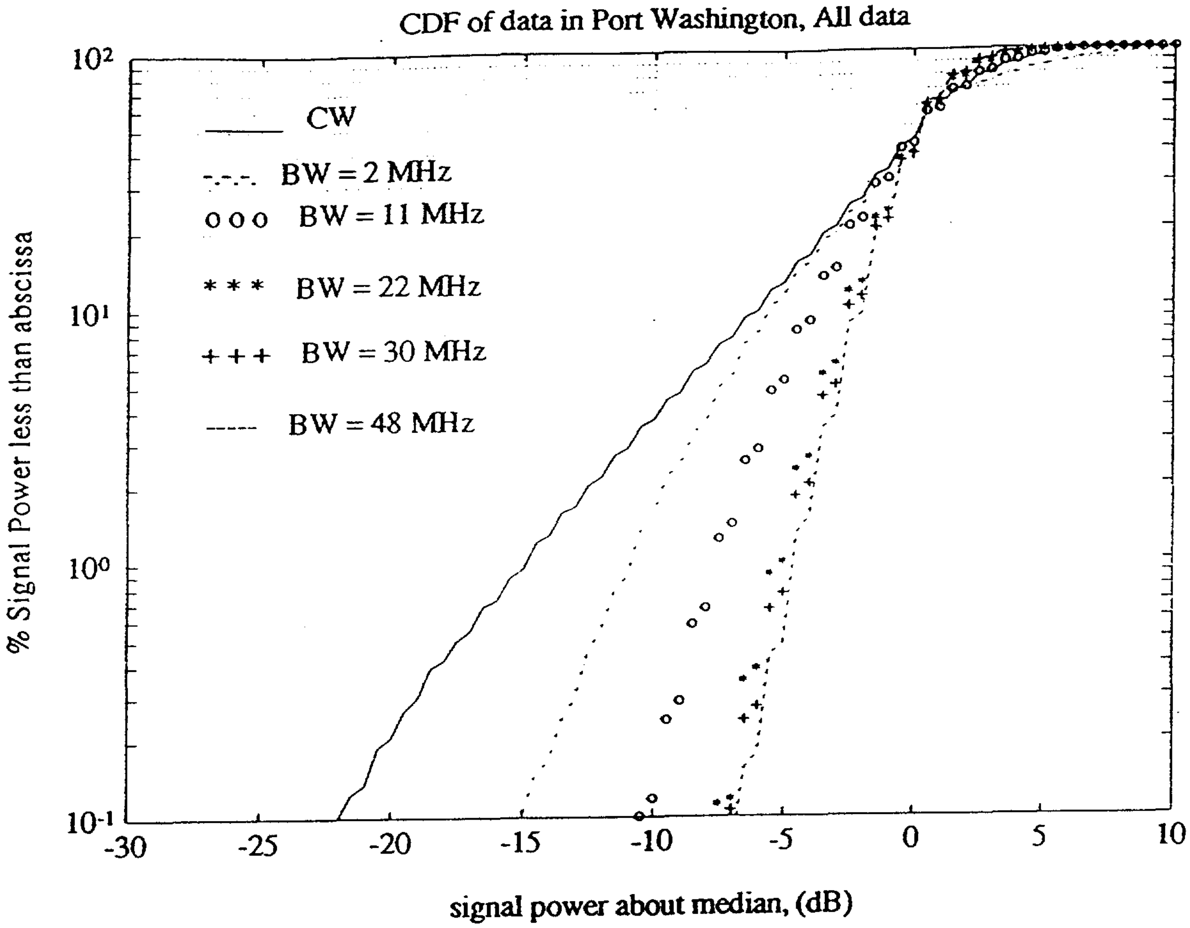
Figures 3.2, 3.4, and 3.6 are redrawn plots of Figs. 3.1, 3.3, and

3.5 for three different probabilities, 10^{-3}, 10^{-2} and 10^{-1}. Note that there is a variation in fade margin of less than 1dB for bandwidths exceeding 20MHz. At 15MHz, a bandwidth under consideration by the Commission, a variation not exceeding 2dB is observed.

It should also be observed that narrowband spread spectrum systems, using a bandwidth of about 1MHz, require a fade margin of 15 - 19dB depending on the environment. (These are the numbers for a probability of 10^{-3}).

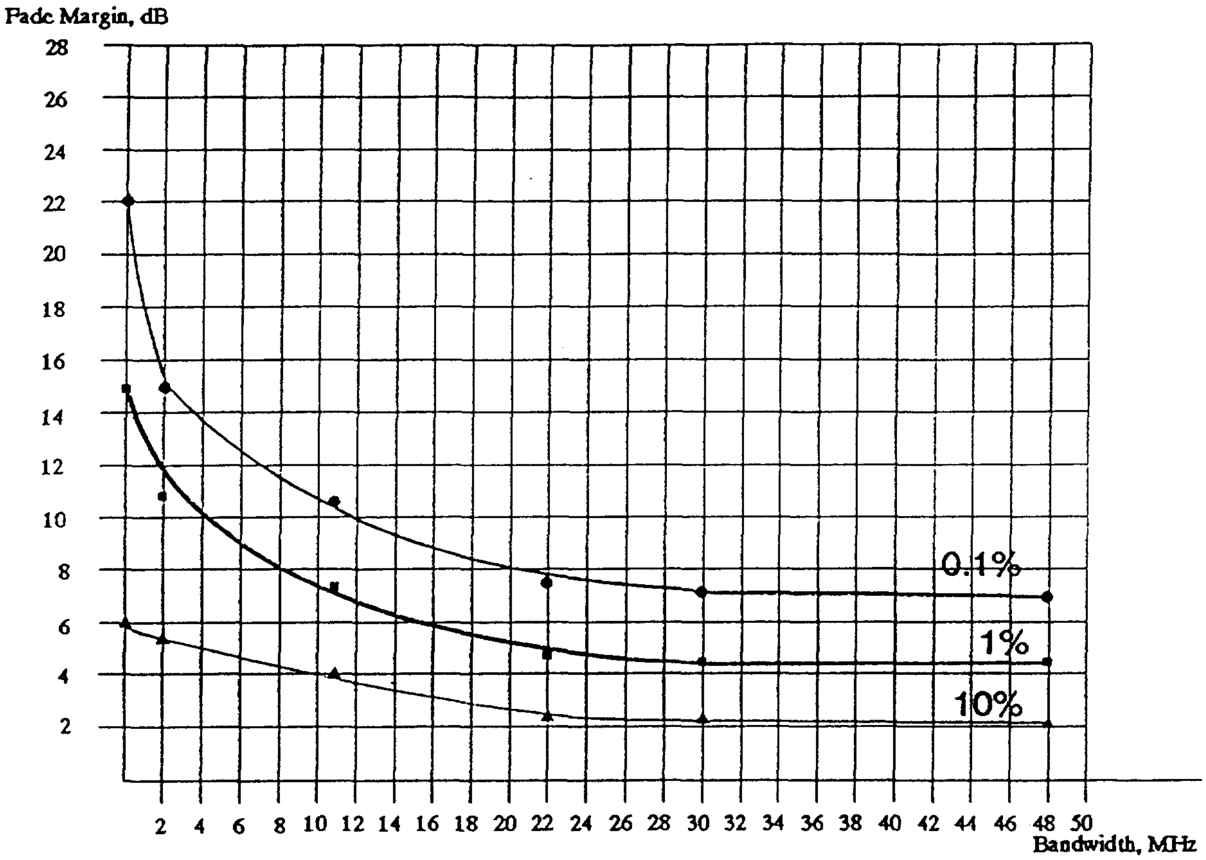
3.3 Observations

It is observed from the data that the required fade margin increases as the bandwidth decreases, and increase in fade margin becomes significant at bandwidths less than 11MHz.



CDF of data in Port Washington, All data
CW
BW = 2 MHz
BW = 11 MHz
BW = 22 MHz
BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
signal power about median, (dB)
10^2
10^1
10^0
10^{-1}
-30
-25
-20
-15
-10
-5
0
5
10

FIGURE 3.1



FADE MARGIN IN PORT WASHINGTON

FIGURE 3.2

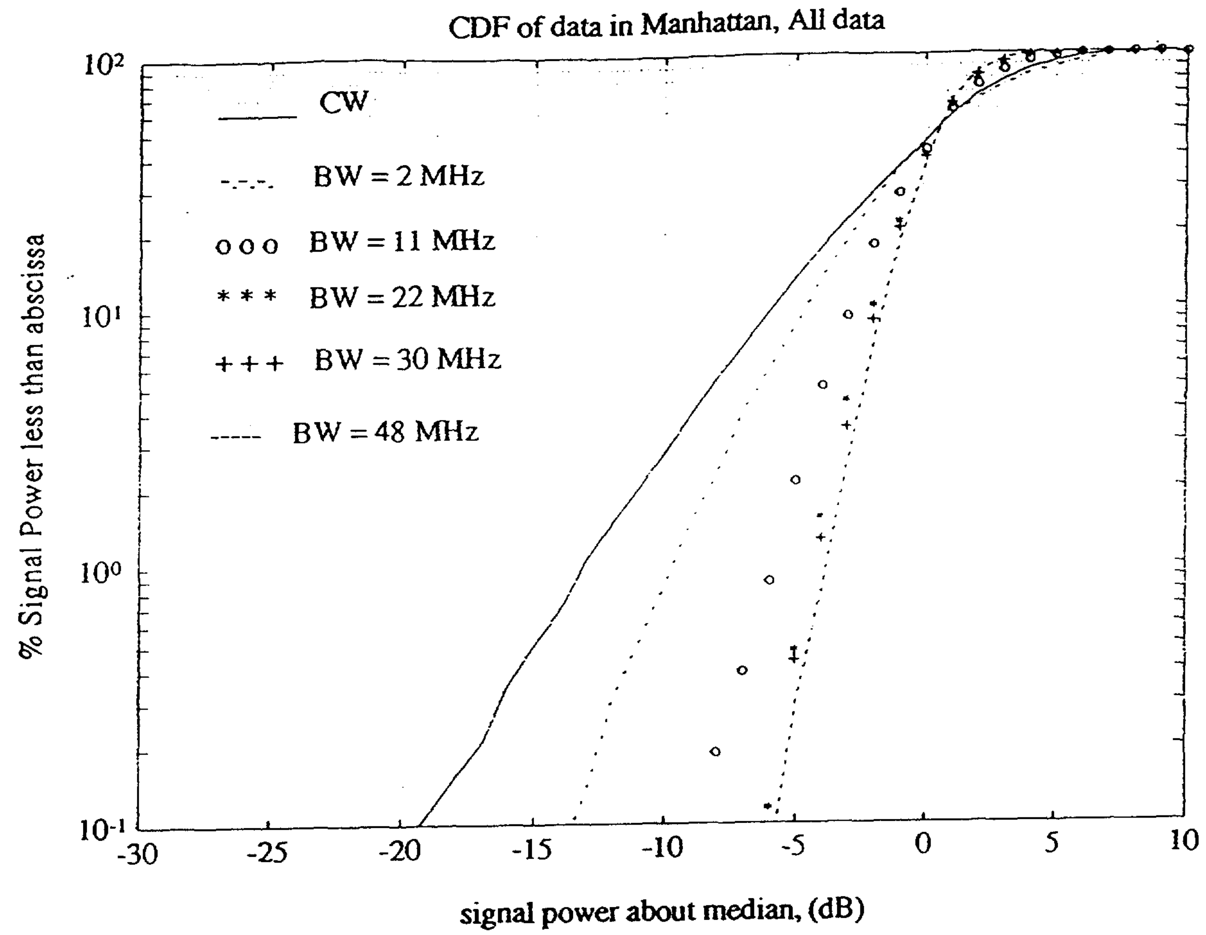
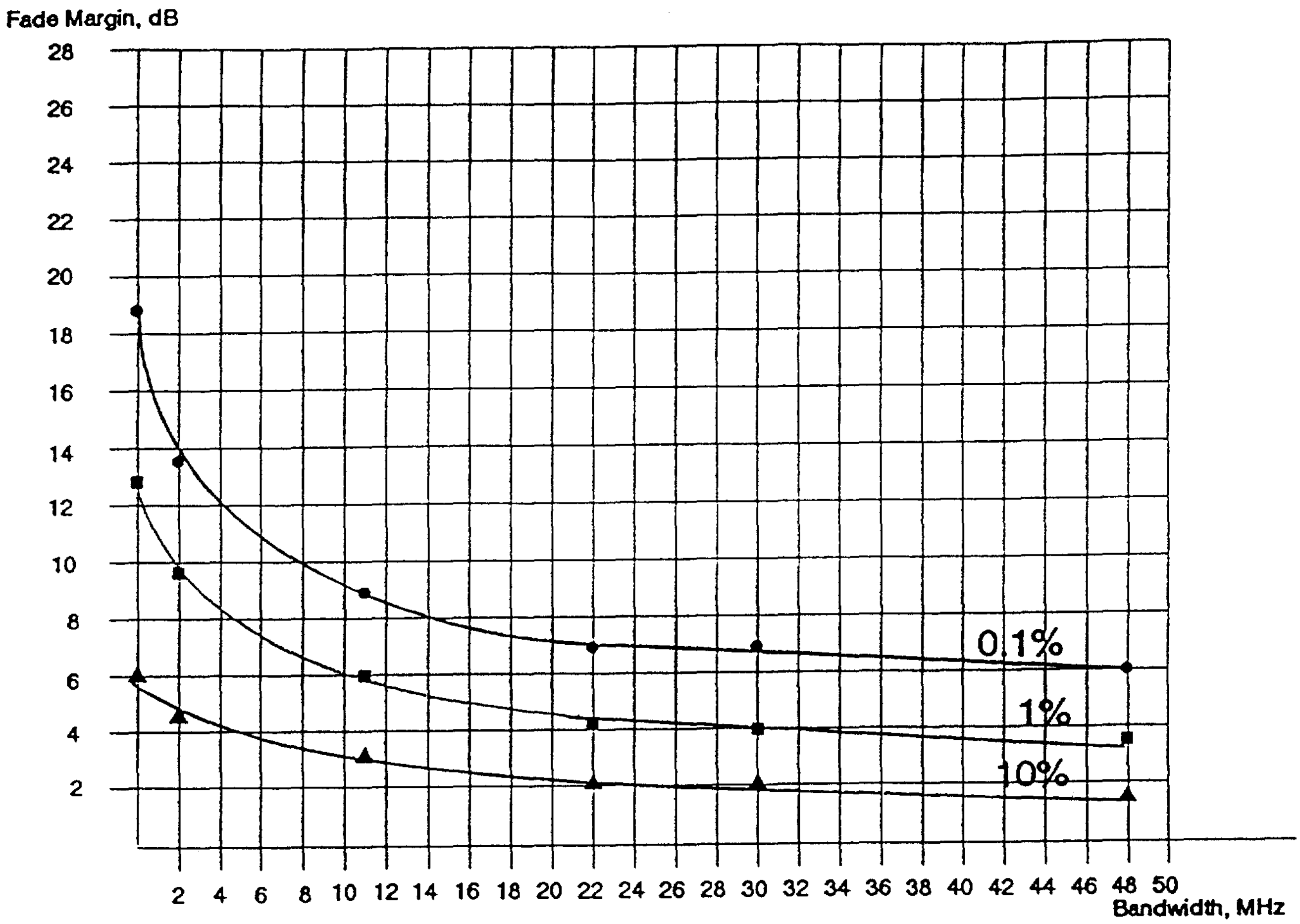

CDF of data in Manhattan, All data
CW
BW = 2 MHz
BW = 11 MHz
BW = 22 MHz
BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
signal power about median, (dB)
10²
10¹
10⁰
10⁻¹
-30
-25
-20
-15
-10
-5
0
5
10

FIGURE 3.3



FADE MARGIN IN MANHATTAN

FIGURE 3.4

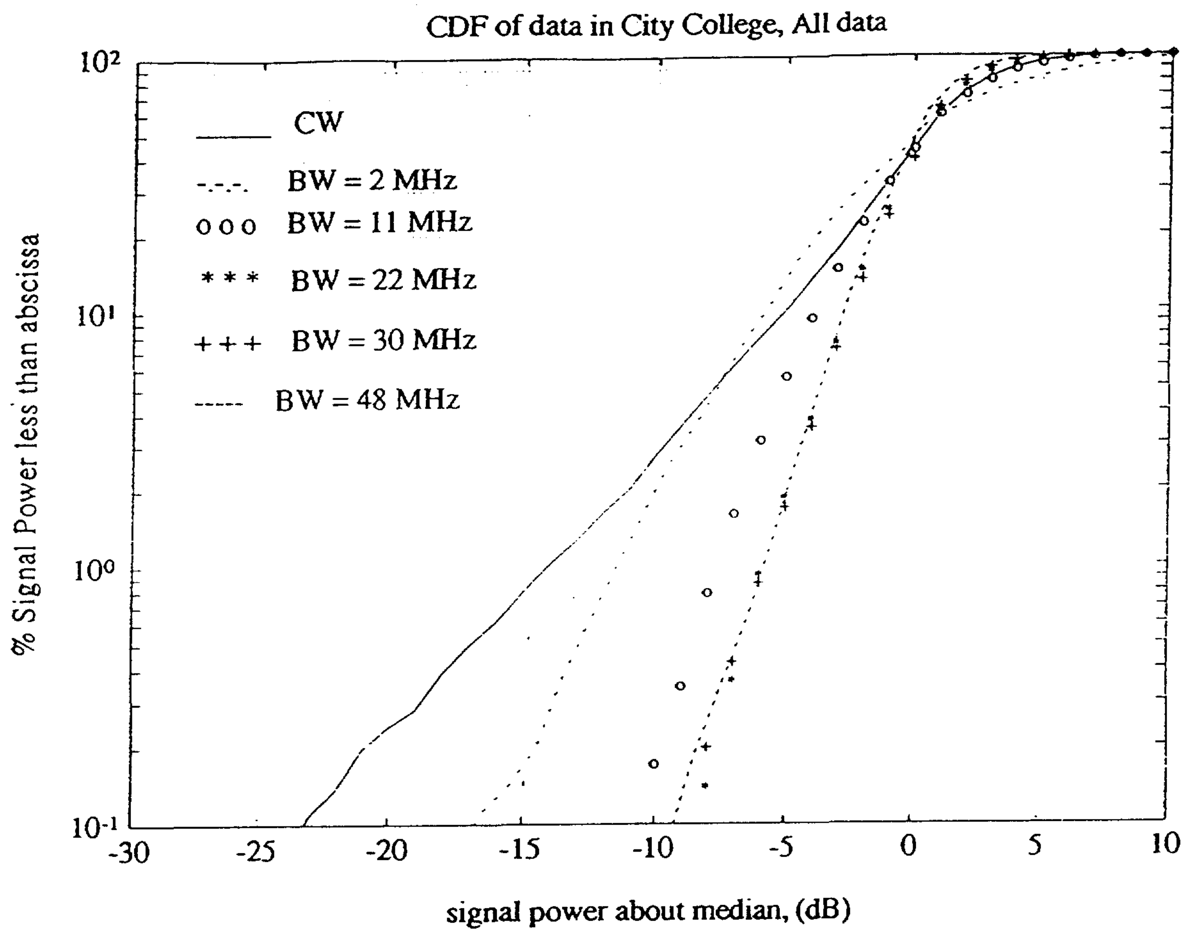
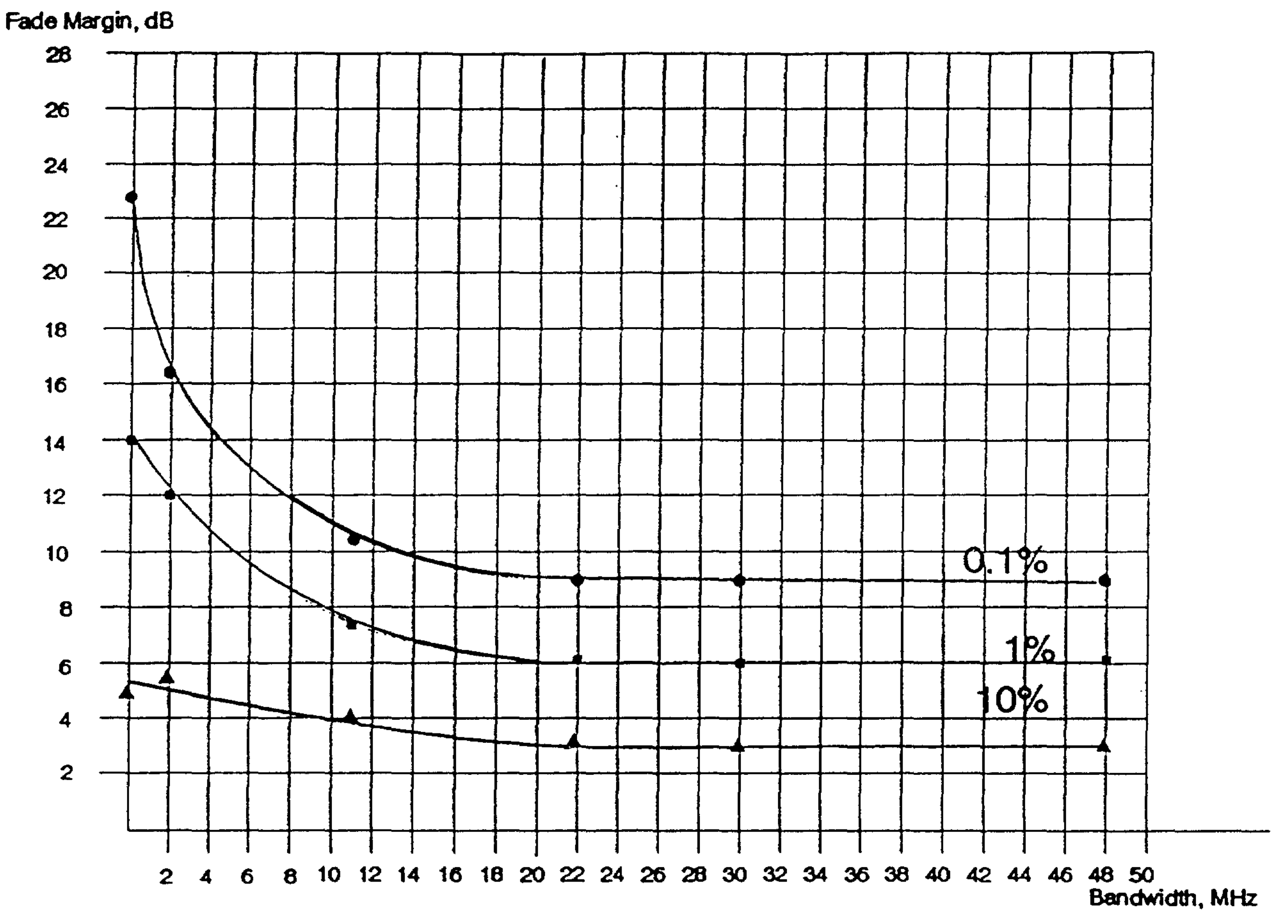

CDF of data in City College, All data
CW
BW = 2 MHz
BW = 11 MHz
BW = 22 MHz
BW = 30 MHz
BW = 48 MHz
% Signal Power less than abscissa
10²
10¹
10⁰
10⁻¹
-30
-25
-20
-15
-10
-5
0
5
10
signal power about median, (dB)

FIGURE 3.5



FADE MARGIN IN CITY COLLEGE

FIGURE 3.6

4.0 MULTIPATH COMPONENTS IN OUT-OF-SIGHT COMMUNICATIONS AT 1.9GHz

4.1 Introduction

In this section we present the results obtained by modelling the out-of-sight communication as a series of signal rays. Typically 15 rays were used in this model although excellent approximate results can be obtained using 2 to 3 rays. The details, leading to these results, are presented in Appendix A.

Figure 4.1 shows two cross streets. The transmitter is placed on one street, a distance d_1 from the corner. The receiver is placed in the cross-street, out-of-sight of the transmitter, a distance d_2 from the corner. For each pair of distances, d_1 and d_2, chosen, the rays leaving the transmitter and received at the receiver are determined along with their amplitudes and times of arrival. The results are shown in Figs 4.2 - 4.31.

4.2 Discussion of Results

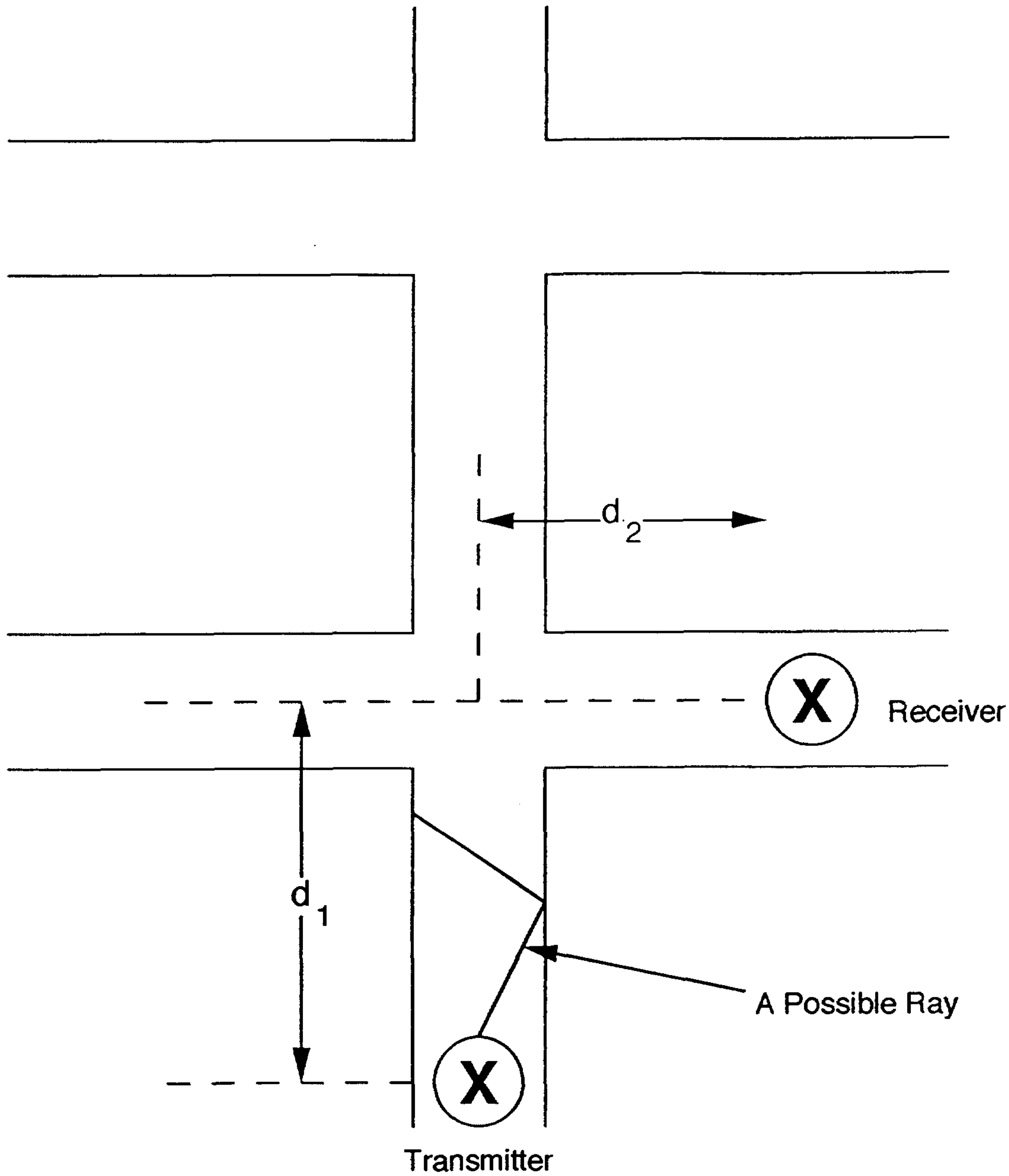
Figure 4.2 shows 15 rays obtained when d_1 = 100m and d_2 = 10m. Note that there are two large amplitude rays, one at an angle of about 52° off-of-"boresight" and the other at the angle of about -65° from "boresight". Boresight, as seen in Fig. 4.1, is a line drawn along the middle of the street. Figure 4.3 shows the delay of each ray in travelling from transmitter to receiver. Figure 4.4 is an expanded view of Fig. 4.3 which shows that the two largest signal rays are about 30ns apart. The other rays can be neglected, since, as seen in Fig. 4.2, their amplitudes are more than 3dB below the large-ray signals.

Note that since the two, almost equal amplitude, rays are delayed from one another by 30ns, fading will occur if a spread spectrum system, having a chip duration exceeding 30us, is used. This corresponds to a bandwidth of about 35MHz.

Figure 4.5 shows that as the receiver moves further into the block the 15 rays are more evenly distributed about boresight. Note that now there are about 3 signal-rays of comparable amplitude. Figure 4.7 is an expanded view of Fig. 4.6 and shows that the two largest signals are about 15ns of one another. The third large ray is about 65ns from the first signal. Thus, if the chip duration is less than 65ns, only two, rather than three, rays contribute to the fading. A chip duration of 65ns corresponds to a bandwidth of about 15MHz.

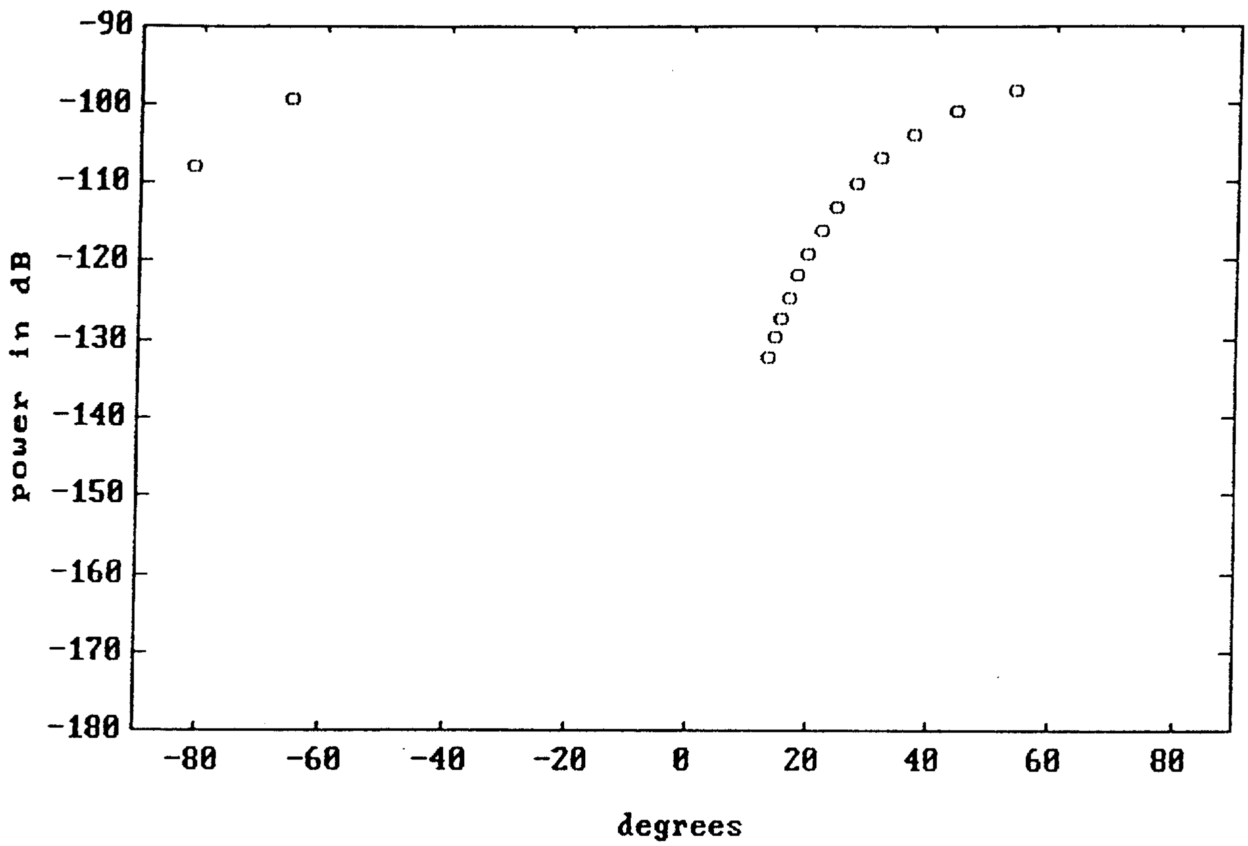
Figures 4.8-4.10 show delays of 30ns for the large amplitude signal rays, requiring a 35MHz bandwidth to minimize fading.

The remaining figures (Figs. 4.11 - 4.31) show similar results, which indicate that B-CDMA, with its wide bandwidth, minimize fades significantly more effectively than a system which has a chip duration exceeding 1μs. As seen from these figures, a narrowband spread spectrum system having a chip rate of 1Mb/s and hence a chip duration of 1μs would encompass almost <u>all</u> of the multipath rays, thereby producing significant fading. <u>This fading could not be resolved by using a RAKE receiver</u>.



A Typical Set of Cross Streets

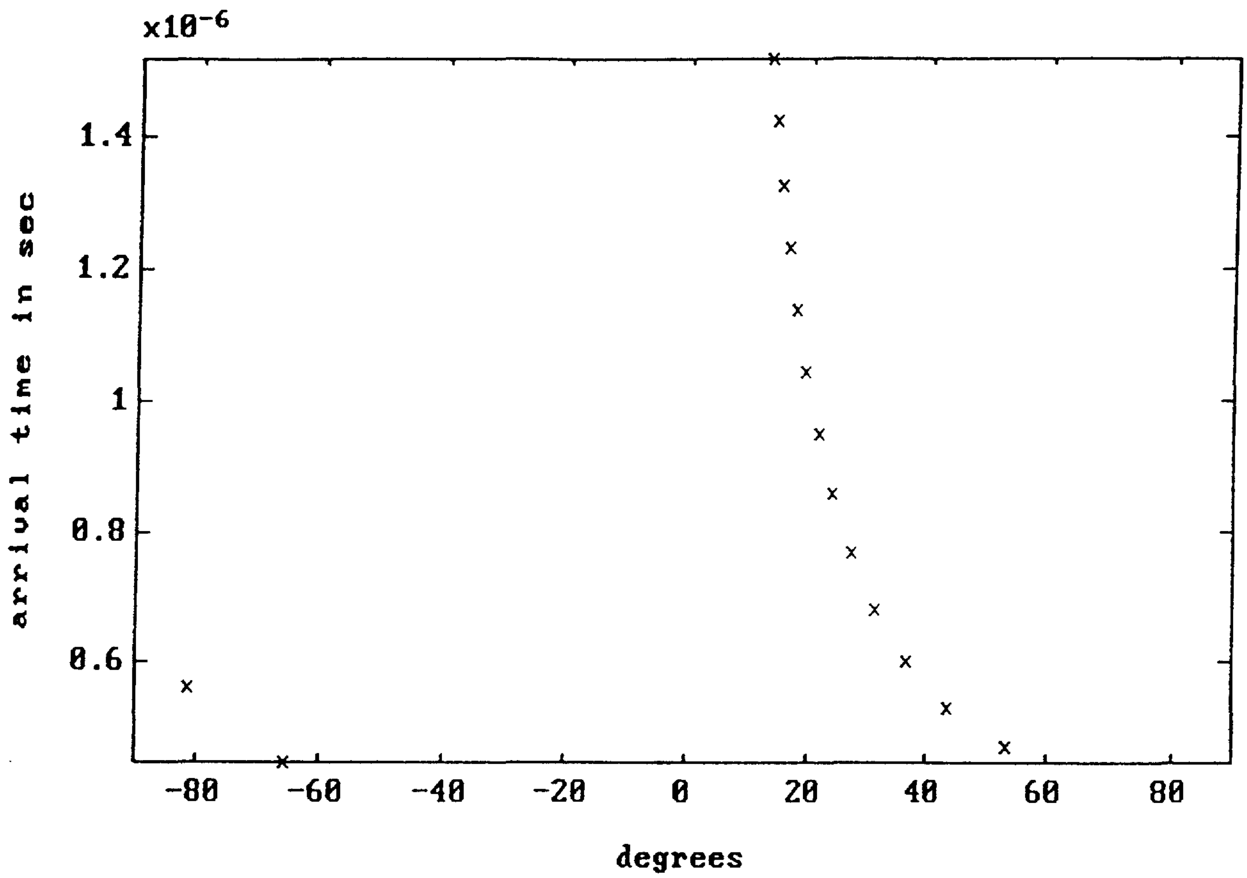
FIGURE 4.1



d_1 = 100 meters

d_2 = 10 meters

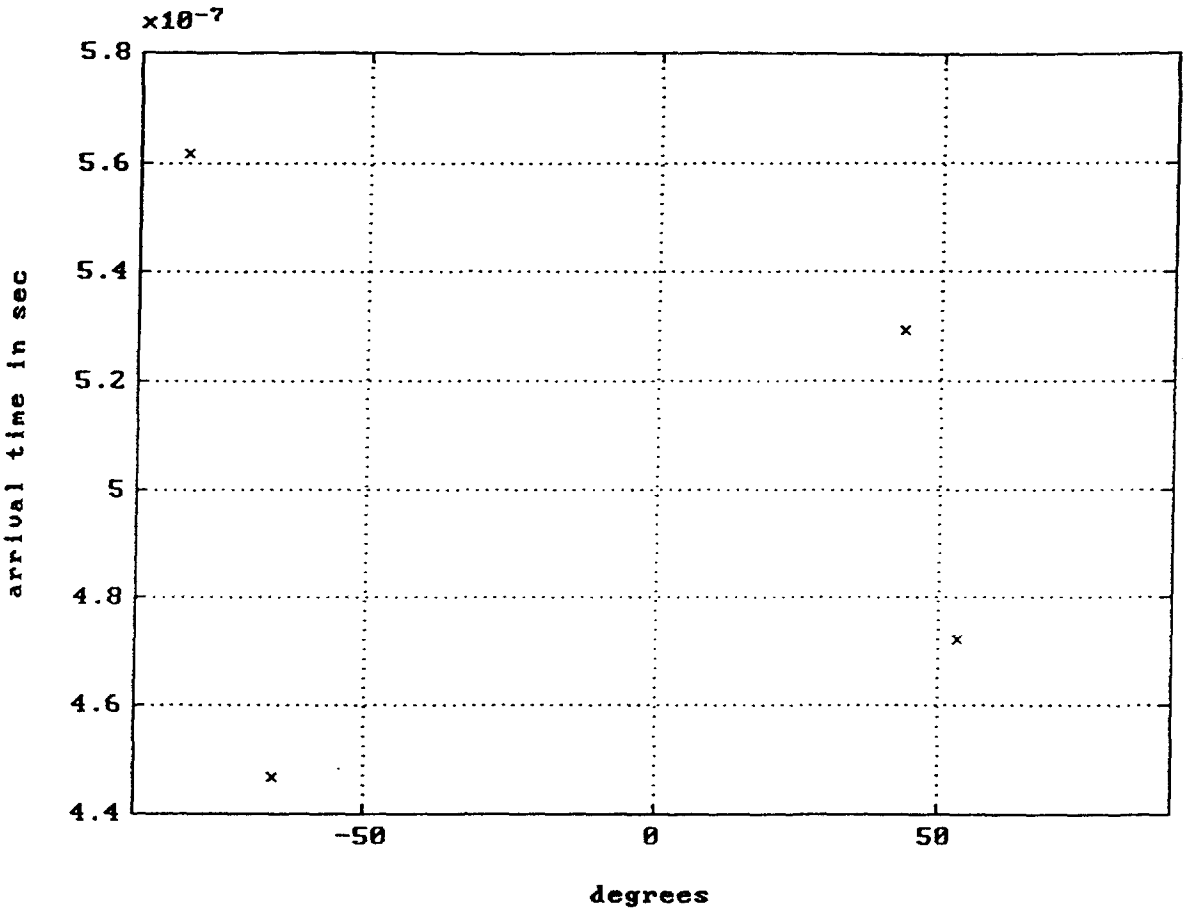
FIGURE 4.2



$d_1 = 100$ meters

$d_2 = 10$ meters

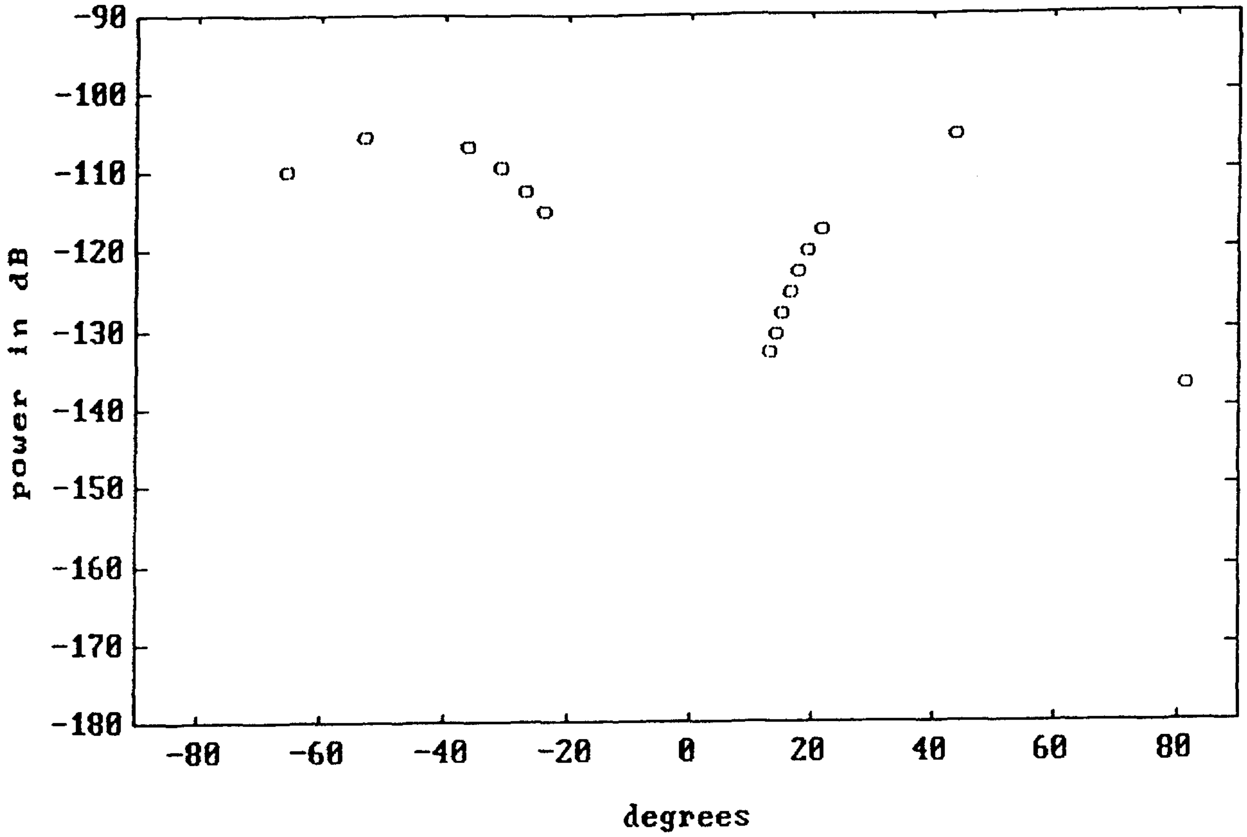
FIGURE 4.3



$d_1 = 100$ meters

$d_2 = 10$ meters

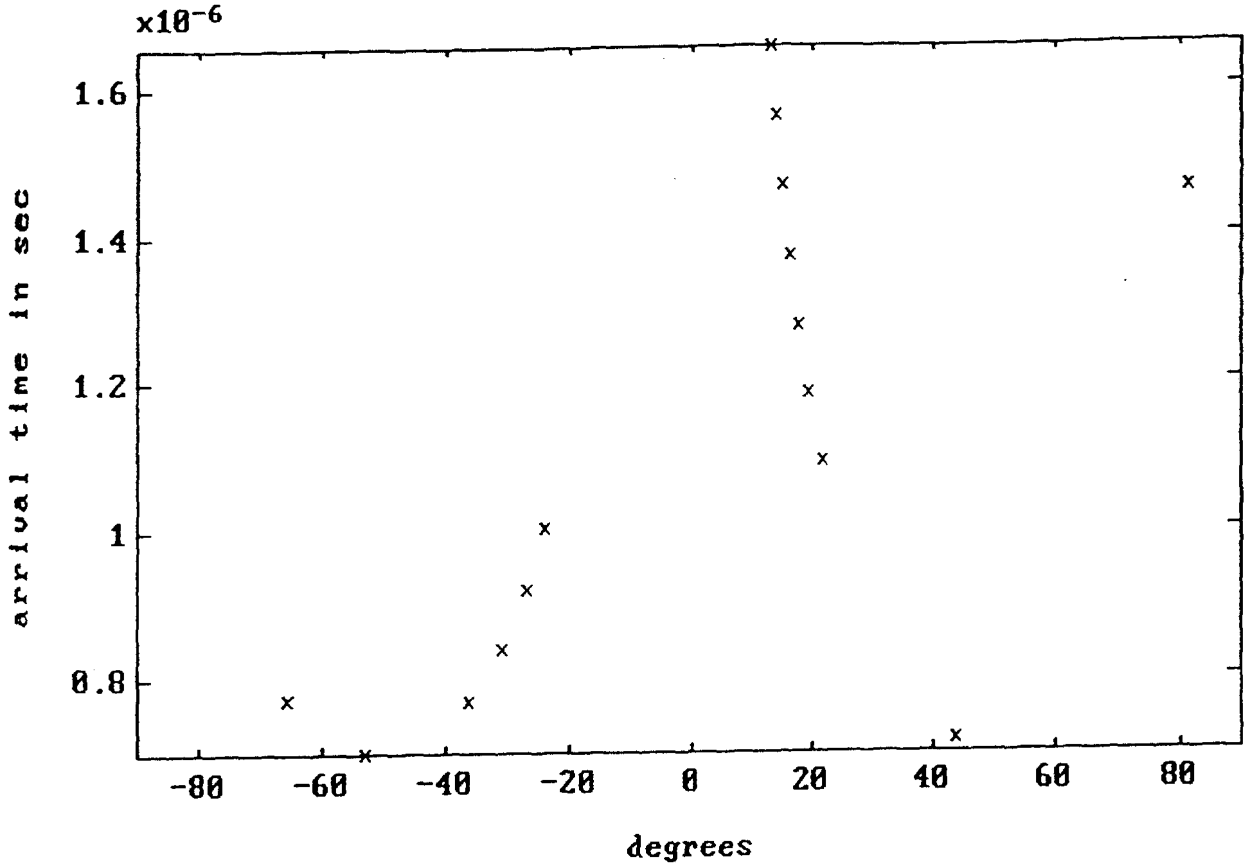
FIGURE 4.4



d_1 = 100 meters

d_2 = 50 meters

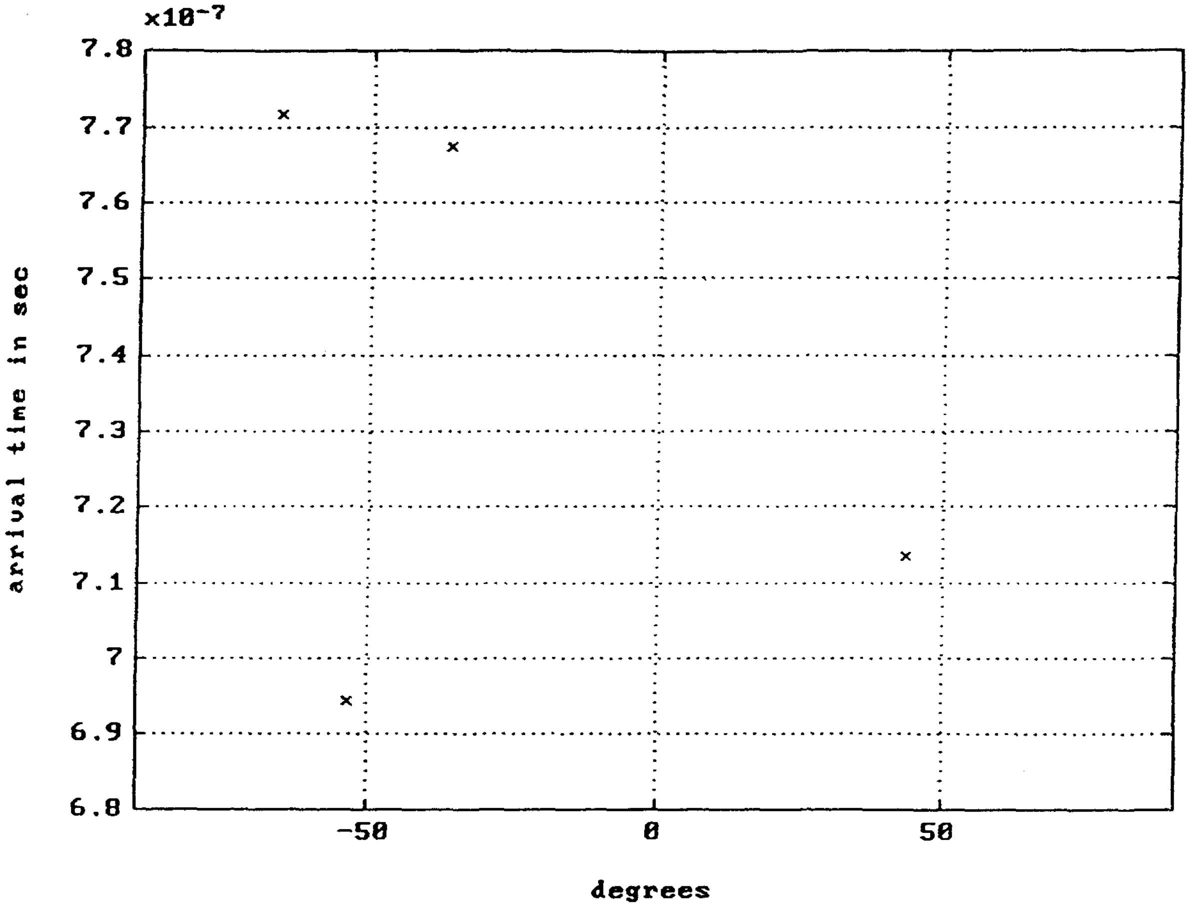
FIGURE 4.5



d_1 = 100 meters

d_2 = 50 meters

FIGURE 4.6



$d_1 = 100$ meters

$d_2 = \ 50$ meters

FIGURE 4.7